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THE DEVELOPMENT AND TESTING OF A RADIO WHALE TAG

by

William A. Watkins
William E. Schevill

September 1977

TECHNICAL REPORT

Prepared for the Office of Naval Research (Biological Oceanography Section) under Contract N00014-74-C-0262; NR 083-004.

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THE DEVELOPMENT AND TESTING OF A RADIO WHALE TAG

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Abstract

A 200 mwatt, 27 MHz radio whale tag has been developed for tracking whales at sea. It is remotely implanted and will transmit continuously for about 90 hours, equivalent to 16 weeks on a normally behaving finback. The tag has resulted from initial efforts to tag right whales with radios in 1961-1965. The tag and its launching system were tested on whale carcasses at the Icelandic whaling station in 1976 and 1977. One point shape consistently penetrated straighter and better than others we tried. With 1977 modifications, the radio whale tag appears to be ready for field trials on rorquals.

Introduction

A means of following the movement of whales is important to an understanding of their biology as well as being necessary to their conservation and regulation, (see Norris, Evans, and Ray 1974). A radio tag has been developed, therefore, to try to track whales. This report describes the steps that have been taken in the development and the tests of the radio tagging system. We hope this narrative will reduce repetition of unnecessary steps in further tagging efforts, clarify some of the inherent problems, and provide a helpful background for using the tag.

The emphasis in the development of the radio tag has been to find a system that could be successfully used on finback whales (*Balaenoptera physalus*) at sea. This is a stringent goal, since these whales generally are very difficult to approach.

Ideally, a radio whale tag should provide an identifying signal whenever the whale is at the surface so that the tagged animal can be relocated (telemetered data from the periods between surfacings is an obvious refinement not considered here). The tag should be attachable from a distance of tens of meters at least since whales are not easily handled at sea, and many cannot be approached closely enough to attach it manually. The tag should disturb the whale as little as possible, and the life of the tag should be long enough to provide information on relatively long segments of the whale's life pattern —13 or 14 months, preferably.

Early Tags

Our first efforts to develop such a tag began in 1961 with the building of a small transmitter and consideration of methods of attaching it to right whales (Eubalaena glacialis). Transistor circuitry had developed so that high frequency oscillators could be made to fit into small pressure cases, but the big problems then (as now) were finding power supplies of sufficient capacity and adequately rugged antennas. We experimented with minute power matched by extremely sensitive receivers. We tried saltwater batteries, built cases of different metals to utilize galvanic action, and finally used batteries that were always too large. We tried high frequency to keep antennas small, and experimented with lower frequency antennas including coils, plates, and floating radiators.

During 1962, 1964, and 1965 we tried a succession of radio tag designs on right whales (Schevill and Watkins 1966), and though we were unable to track the animals, we had a good introduction to radio tagging. Our best tag (1965) was in a 1.5 cm x 15.5 cm cylindrical case with a wire antenna at one end and a barbed point at the other (Figure 1). The tag was attached by dropping it on a weighted pole from a

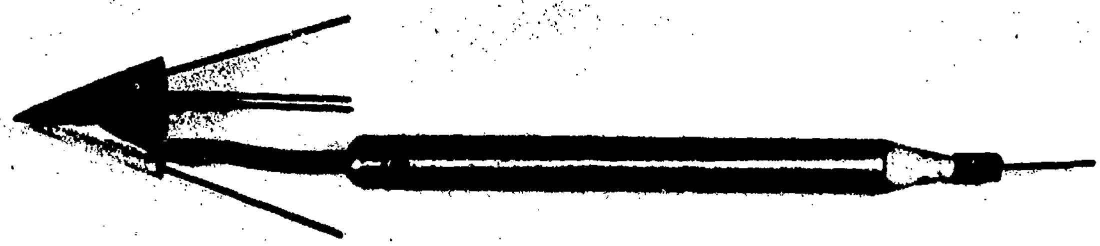

Figure 1. 1965 radio whale tag, used on Eubalaena glacialis. The tag was attached by dropping it on a weighted pole from a helicopter.

helicopter so that the tag penetrated to the base of the antenna and the pole was then released and pulled back. The transmitter circuitry operated only when the antenna was clear of the water surface. We used 140 MHz at 1 mwatt, and in tests on intermittently submerged buoys, these tags gave too short a range for tracking from surface vessels, but provided adequate distances (up to 80 km) for aerial reception.

We were successful in implanting the tags in the whales, but tracking was frustrated by damaged tags, competing radio-frequency noise, and movement of the whales away from our area. But our main difficulty was the lack of adequate directional receiving gear. A rapid indication of direction was needed for the very short (2 sec or less) signals that were transmitted when the tag appeared at the surface. We tried multiple directional receiving systems but found that they were too cumbersome and their indications of direction were too broad for reliable use. We needed a portable, sensitive, automatic, radio direction finder, which was not then available.

The next few years saw the commerical development of small radio beacons for use in the recovery of instruments at sea (Martin and Kenny 1971) and their adaptation to the tracking of porpoises (Evans 1971). Portable automatic radio direction finding gear was developed and specifically adapted for animal tracking (Martin, Evans, and Bowers 1971), and these systems were used in tracking several species of the smaller cetaceans. The methods of attachment have required that the animal be captured and the equipment fastened in place, which usually meant that only animals that could be caught and handled could be tagged. Larger whale species have also had radios attached to calves that were restrained (Norris, Evans, and Ray 1974, Norris and Gentry 1974). A radio tag attached to a small captive gray whale provided temperature and depth information as well as a track of its movement after it was released (Evans 1974).

Remote Attachment

With the development and demonstrated potential of a portable automatic radio direction finder (ADF), our attention turned again to the design of a radio tag that could be used at sea on free-swimming whales, especially finbacks. Remote attachment was a requirement for this, and so was the ability to track from surface vessels as well as aircraft. We started therefore with the frequency range (27 MHz) and powers (200-300 mwatt) that could readily be received by existing ADF systems, and we began a program of development and testing that we hoped would produce a useable tag. With our previous tests as background, we chose to try for a system that would deliver the radio tag from a ship (we hoped from a standard shotgun) and penetrate the blubber, leaving only an antenna outside. The transmitter would operate only during the times the antenna was out of water as the whale surfaced, using the latest in battery designs in order to achieve a long life in small size. We hoped to keep the development of the radio tag as open as possible, so that the program could benefit from the ideas and suggestions of others, and so that our experience could be used by others.

We began experiments in 1973, monitoring the radio bands for useable frequencies, obtaining FCC allocations, purchasing an ADF (Ocean Applied Research), and testing floating beacons for overwater transmission characteristics. By 1974 a suitable 27 MHz transmitter was miniaturized and packaged to withstand the stress of rapid accelerations. A conference of individuals interested in tagging larger whales was informally convened in LaJolla, December 1974, to discuss the shape of the radio tag and methods of remote delivery and attachment. (Those in attendance included Evans, NUC; Ray and Wartzok, JHU; Maiefski, OAR; Mitchell, EC; Perrin, NMFS; Schevill and Watkins, WHOI). Ocean Applied Research (Maiefski) agreed to work with us in this development and undertook (contract with WHOI) to work on ballistics of the tag so that it could be shot from a gun, on the development of an antenna that would tolerate this, and on the attachment mechanism. Other investigators, particularly Evans, Ray, and Wartzok, joined the effort and supplemented our input with ideas and funds, particularly contributing to the system of launching the tag. The radio tag system was tested at San Diego on a piece of bowhead whale blubber, with the hope that it was ready enough for field trials on bowhead whales (Ray and Wartzok MS 1975). The pushrod design and the point shape had developed without our input, and we saw the complete radio whale tag with its launching pushrod system for the first time at the Santa Cruz conference on the biology of marine mammals, December 1975.

Up to this point, our efforts had been to devise a radio tag that was rugged enough to be shot from a gun. Now we began to look more closely at the tag and to try to assess its reliability. With this closer scrutiny and with thought of the rigors of use at sea, the faults in our design became more prominent. We did not want to release the system for use until we knew it would work well.

The Radio Whale Tag

The radio whale tag (produced by Ocean Applied Research, San Diego) is a 200-mwatt transmitter mounted on a 1.1 cm by 10.5 cm printed circuit board and fitted into the upper end of a stainless steel tubular case. The size of this case, (1.9 cm in diameter and 24 cm long, outside dimensions) is dictated by the size of the power supply, three organic lithium batteries, nominally 3 volts each (Mallory LO 32S). A tapered 45-cm whip antenna of moulded plastic is held in place at the top of the tag by a 4-cm penetration-stop disc flange. The tip of the antenna has a metal water contact for shutting the transmitter off underwater. The lower end of the case is fitted with two hinged barbs and a penetration point, together about 5 cm long. Thus, the complete tag is 29 cm from point to flange, designed to be imbedded in the blubber with only the antenna protruding (Figure 2).

The launching system for the radio whale tag uses a detachable hollow pushrod that fits into the gun barrel and over the antenna and pushes against the penetration-stop flange. Fastened to the pushrod and

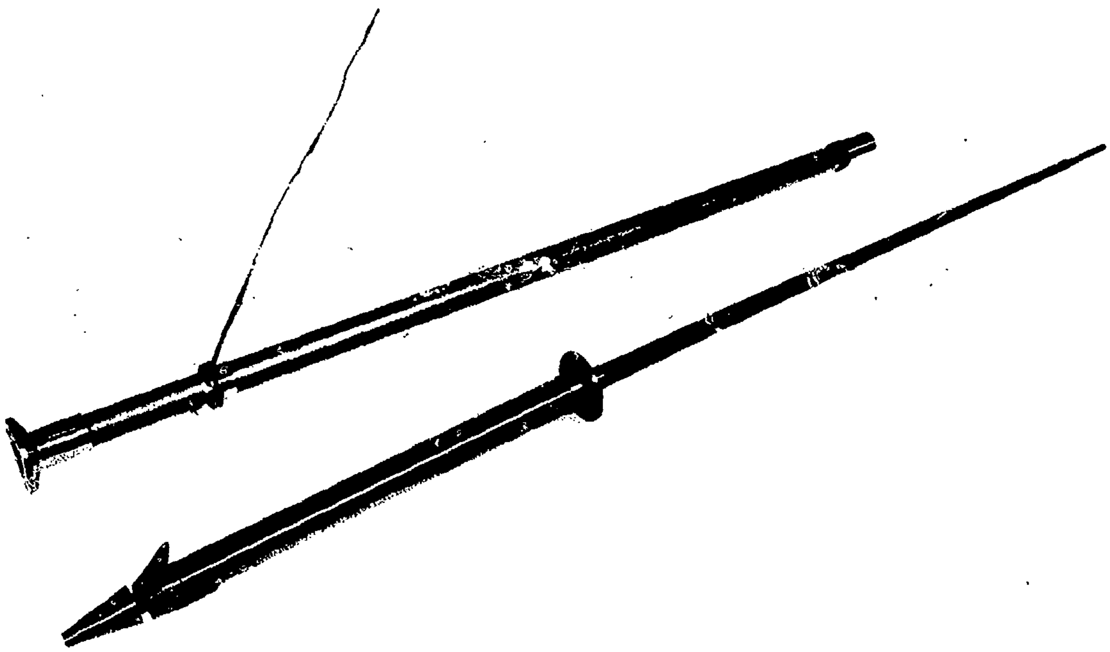

Figure 2. 1977 radio whale tag: pushrod and complete tag.

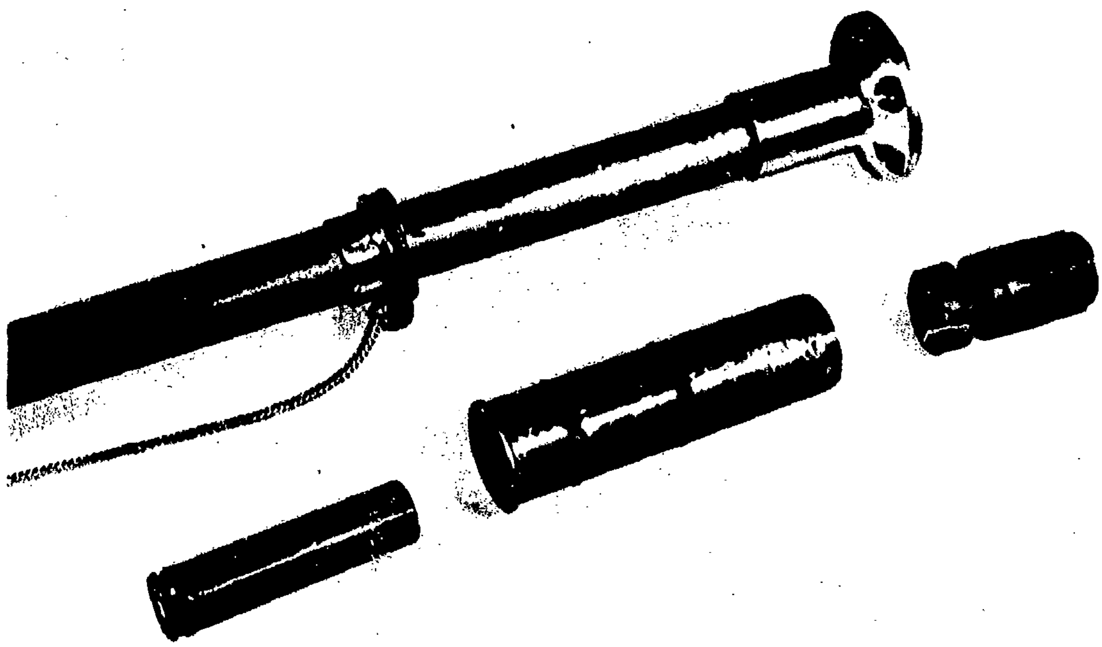

Figure 3. 1977 radio whale tag: pushrod with line ring and flange, cartridge, chamber adapter, and gas seal.

allowed to pay out as the tag is fired is a line that provides stabilizing drag for the tag in flight and permits retrieval of the pushrod or the entire tag if the shooter misses the whale. The pushrod is secured to the tag with break-away fastenings.

The launcher for the tag is a standard 12-gauge shotgun, with 7-cm cartridge chamber. The gun is weighted to reduce the kick of firing the 550-g. tag and pushrod assembly. A specially loaded shell (OAR) is used with a chamber adapter and a gas seal fits into the adapter and over the end of the pushrod (Figure 3).

1976 Tests

Our first complete radio whale tag was delivered in April 1976, and immediately we began to notice variability in the state of the power supply. Since hermetically sealed units were not yet available, we were using unsealed organic lithium batteries which provided the most power for the space. Later tests showed these batteries to be prone to gas and electrolyte leakage and to have poor shelf-life. Though a number of remedies were tried, including complete potting of the power supply and separate packaging, the battery variability persisted.

We planned tests of the tag system at Woods Hole and then on whale carcasses at the whaling station in Iceland, starting 4 August 1976. Therefore, as soon as tagging equipment became available (15 July 1976), we began testing. Our first test shots were into floating rag-filled targets anchored 33 m away in about 1 m of water. The gun was both hand-held and mounted in a vise during firing.

We were pleased with the way the projectile was propelled in an apparently accurate trajectory. We could hit a small target consistently. The pushrod assembly seemed to provide good protection for the antenna, the transmitter circuitry worked well and survived successive firings, and the ADF receiver provided good bearings (Schevill and Watkins MS 1976). But a number of problems also were discovered. Some of these could be remedied on the spot, some needed factory modification, and some were tolerated for the duration of the tests. The gun was unbalanced and had sharp edges that cut "O" rings and hands. Shear fastenings between pushrod and tag separated too easily. And, the antenna proved to be weak physically. All of the tags were returned to the factory for repair.

The test units returned from the manufacturer on 2 August 1976, a few more test shots were fired into targets, and on 4 August we took the system to Iceland. We experienced excellent cooperation from the Marine Research Institute in Reykjavík and from the shore whaling station of Hvalur H.F. at Hvalfjörður. The tags were tested on fresh whale carcasses (within 20 hrs of capture) by firing the tags into the carcasses as they floated at the base of the ramp leading to the station flensing plan. Firing positions were chosen to simulate as closely as possible the angles expected when working at sea. Because of early difficulties of tag penetration, however, we soon began using higher angles and shorter distances. With the ready cooperation of the flensers we were able to recover the tags and note the various amounts and angles of penetration (Figure 4).

In these tests (Schevill and Watkins MS 1976), we used 6 tags in 18 shots on finbacks, (Balaenoptera physalus) and 2 on a sperm whale (Physeter catodon). (a) The test shots showed extremely erratic penetration, and although a few encouraged us by penetrating as we wanted them to, on most shots the tag turned in the blubber or ricocheted off

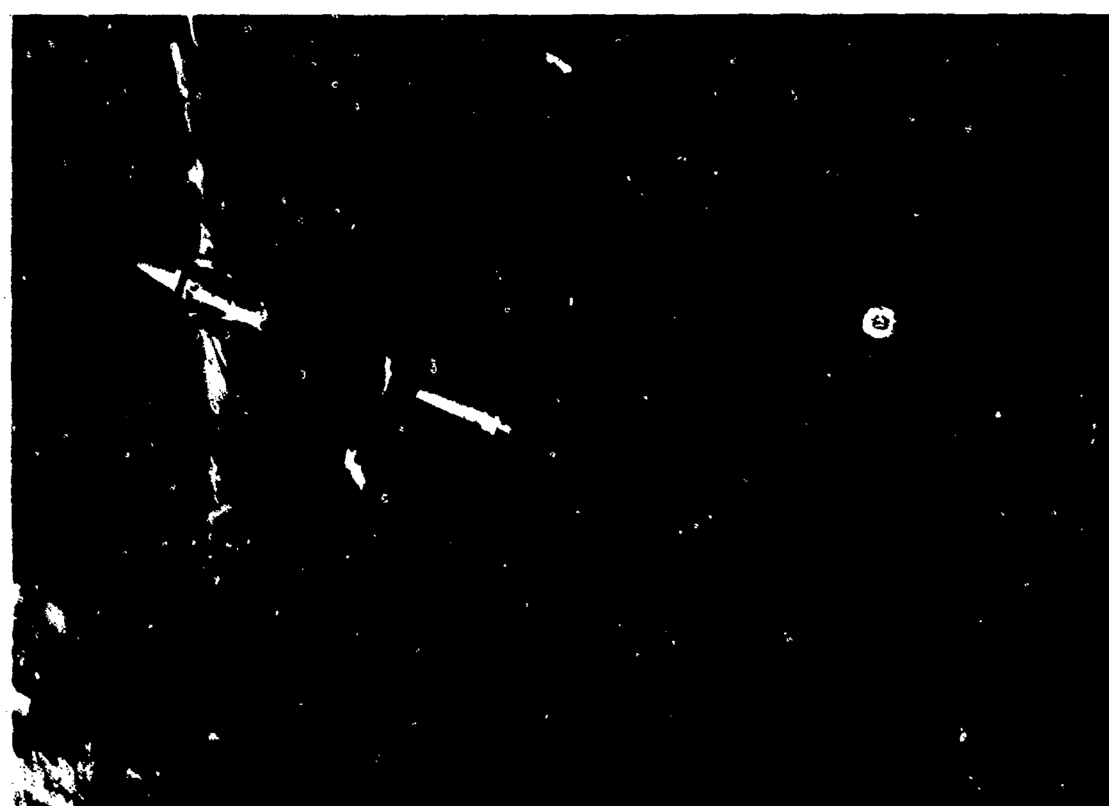

Figure 4. 1976 radio whale tag: shows penetration problem.

the skin. Some turned after penetration so as to protrude from the blubber. (b) The antenna problem was re-emphasized in these tests; they either snapped right off or broke their insulation. Only 1 antenna of the 6 survived 2 test shots. (c) The pushrod sheared its fastenings and was consistently thrown off from the antenna base, sometimes actually smashing the antenna support ring. (d) The cases often leaked, sometimes because of antenna damage. (e) The power supplies all failed; batteries were bent out of shape or burst inside the battery compartment.

The tests in Iceland confirmed the accuracy of the trajectory, allowed development of methods of handling the system for easier use, and showed that the transmitter circuitry consistently survived repeated shots. The tests also had indicated that we needed work on an improved point, a more rugged antenna, a different pushrod fastening system, a water-tight design, and a power supply that could survive the accelerations of firing. The shock of deceleration against the hulk of the whole whale was found to be at least as severe a shock to the tag as that of being propelled from the gun. Tests on fresh whale carcasses had exposed very different problems than previous tests on less realistic targets. We decided not to try implanting any tags in live whales until the faults could be corrected.

At about the same time as our Iceland experiments, two other groups tried the radio tags on live whales using essentially the same

(OAR) tagging system. These tests demonstrated the feasibility of tagging whales with this system and they showed that the tracking worked. Michael F. Tillman and James H. Johnson of the National Marine Fisheries Service, Seattle, tried the tags on humpback whales (Megaptera novaeangliae) 7-21 August 1976, near Juneau, Alaska, and succeeded in tracking one whale for at least six days (Tillman and Johnson MS 1976). The tags also were tried on finback whales (Balaenoptera physalus) 12-25 August 1976 in the Gulf of St. Lawrence, Quebec, by G. Carleton Ray and Douglas Wartzok of Johns Hopkins, with Edward D. Mitchell of Environment Canada (Ste. Anne de Bellevue, P.Q.). They tagged and successfully tracked one whale for a little more than a day (Ray and Wartzok MS 1976), using both aerial and boat tracking. The tag failures and ricochets that these workers all experienced appeared to be explained by the problems we encountered in the Iceland test series.

The variability in the condition of the batteries and their susceptibility to damage during firing was confirmed by continued tests at Woods Hole. We also noted that the tag arrived at the target with somewhat variable orientation, perhaps explaining some of the erratic penetration we had observed. We began to explore the use of high-speed photography to verify the ballistics of the tag.

We again organized a meeting of those that were involved, at Woods Hole (on 4 November 1976), to share suggestions for improving the tag design. Participants (Maiefski, OAR; Johnson, NMFS, Ray and

Wartzok, JHU; Evans, NUC; Shulenberger, NORDA; and Schevill, Moore, and Watkins, WHOI) considered modifications to the tag, including batteries, antenna, water-proofing, and point design. We did not dwell on problems of trajectory or variability in tag orientation because the other problems seemed so much more important. Plans were made for testing as modifications developed and for submitting the improved tag to another series of tests in Iceland.

An exploratory trip was made to the factory of one of the manufacturers of lithium batteries to try to see if any of their construction techniques could be modified to provide more reliable and stronger batteries. Though hermetic sealing was apparently not then available, it seemed a possible answer for the need of a stronger battery case as well as solving the shelf-life and leakage problems. Subsequently, we have found hermetically sealed organic lithium batteries of suitable size (Mallory LO 32S) and have modified the tag to fit.

Extrapolating from our tests of these sealed batteries (Mallory LO 32S), we calculate that the radio tag attached to a finback whale could last as long as 16 weeks. This is based on our observations (off Cape Cod) that over extended periods finback whales average about one blow per minute with 2-sec average time at the surface, 120 sec each hour. In bench tests, the transmitter operated continuously on a set of three LO 32S batteries for about 90 hours (drawing 120 ma during transmissions and 27 ma between).

A new, stronger antenna was redesigned electrically by OAR for the tag, and its base was sealed better against water leakage. A test unit that included the improved antenna was tested hydrostatically at Woods Hole (WHOI Pressure Test Facility #77-5). The tag was cycled without any leaks at a test pressure of 350 kg/cm^2 (5000 psi), equivalent to a depth of about 3500 m.

Ballistics

As soon as the modified tags were avilable, we began testing them on targets (cardboard boxes filled with rags). Experience with the tagging gear had made us more confident in the system and allowed us to focus on irregularities. The variability in apparent orientation of the tag as it arrived at the target had been noted previously, but now began to be bothersome. None of our variations in components had affected this. The tags arrived at the target at different angles and the pushrods nearly always sheared their fastenings and went flying off in different directions — all indicative of a highly variable trajectory.

To discover what was happening we tried high-speed photography of various segments of the trajectory of the tag. We used a Fastax WF 3 (Wollensak) movie camera with a 50 mm, F 2 lens, and powered the motors with 24v DC, giving about 1200 pictures-per-sec at a shutter speed of about 1/3000 sec. We used Kodak RAR 2498, 16 mm film. A free standing scale was set immediately behind the portion of the trajectory that was being photographed, providing a reference gauge of distances and relative levels.

On the first photographs, we were startled to see the radio tag break loose at the beginning of its trajectory. Most of the fastenings between the tag and the pushrod sheared immediately on firing, and as the pushrod moved out of the barrel of the gun, the tag assumed a steeper and steeper downward angle. Our analysis was that the tag, protruding from the muzzle, resisted the sudden forward acceleration by the pushrod because of the forces of inertia and the downward pull of gravity. The fastenings were sheared by the difference (90°+) in direction of forces, and the point of the tag dropped sharply downward from its flight path. With the tag and pushrod proceeding at different angles of orientation, it was no wonder that the tag penetrated the target erratically. Photographs of repeated shots showed that this separation was consistent — the tag separated from the pushrod on every shot.

Wartzok (JHU) and Maiefski (OAR) came to Woods Hole with other tagging equipment and we again photographed tag trajectories, trying to devise modifications that would keep the tag from separating.

We did not want then (May) to start over with a new design, but our old one began to look hopeless. Whenever the connection between pushrod and tag was loose, the fastenings sheared, and when the connection was solidified, the pushrod could be seen to bend severely, and then the combined tag and pushrod assembly would swing wildly in flight. To correct the flight, we tried increasing drag and adding corrective planes. We used different retrieving lines. We tried rubber gaskets to hold the joint rigidly but allow some movement. We could make some improvement, but not enough for stable flight.

Finally, it was suggested (by Maiefski) that a spring-loaded connection between tag and pushrod might allow sufficient movement to keep fastenings from breaking, and then permit the tag and pushrod to re-align themselves during the flight. This we tried (Figure 5) by simply inserting coil springs beneath the heads of the nylon shear screws. It worked. The tag separated momentarily from the pushrod and turned downward from the trajectory. But in flight, the tag and pushrod were re-aligned by the springs and by the increasing drag. There was still some wobble between tag and pushrod along the trajectory, but this could be reduced somewhat by adjustment of spring tension.

The orientation of the entire tag and pushrod assembly now varied vertically as it progressed along its flight path, but this variation proved to be repeatable. Photographic sequences of successive shots taken at the same point in the trajectory each showed the tag in nearly identical orientation. Upon firing, with the line of sight about horizontal, the tag turned downward and pulled away from the pushrod, while the tail of the pushrod moved upward as it emerged from the barrel. At 3 meters, tag and pushrod were not quite in alignment and had a downward angle of about 5 to 7°. At 6 m, this downward angle had increased to 8 to 10° and the tag was in line with the pushrod. At 12 m, however, the wobble was diminishing and tag and pushrod were beginning now to turn upward. At 18 m, the upward angle had increased to 3 to 5°. Perhaps we could choose a point that would minimize the effects of these variable vertical angles.

We were encouraged to note that tag and pushrod now stayed together as the target was penetrated, and we began to notice that the tag was going deeper into the target. Now that tag and pushrod were flying together, we found that we could reduce the number of shear fastenings to make it easier to separate the pushrod after implantation.

Accuracy also seemed to improve with the modifications. The radio tag is propelled at a muzzle velocity of only about 70 m per sec, and drops vertically about 1.5 m at a distance of 10 m. The lateral accuracy of the tagging system is highly reproducible but because of the drop with distance, vertical accuracy depends on the marksman's judgment of distance. At sea, such distance judgments would be

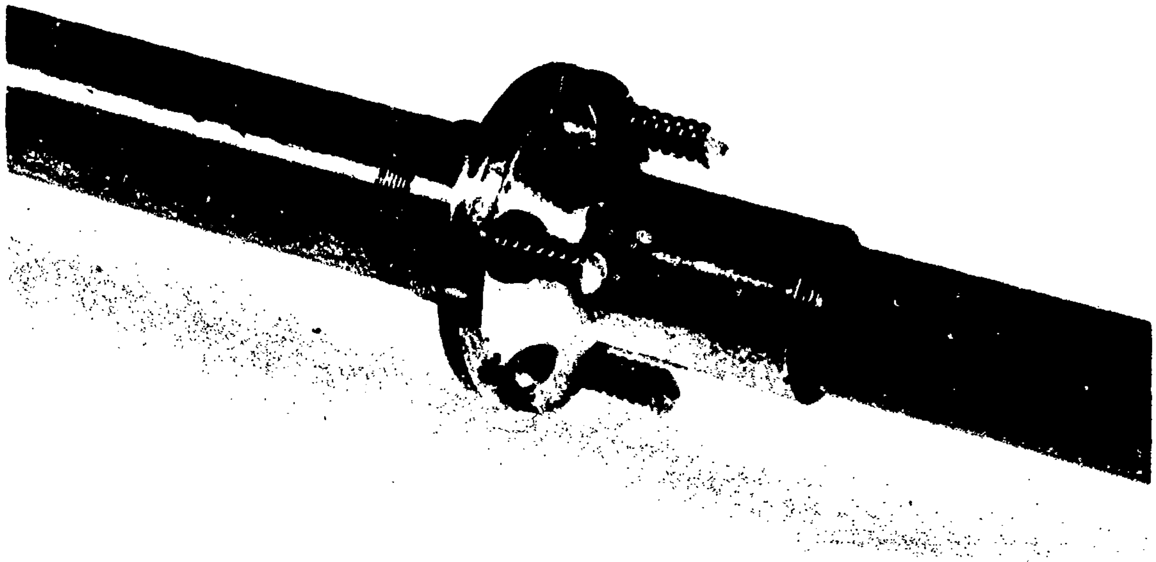

Figure 5. 1977 radio whale tag: spring-loaded connection between pushrod and tag penetration-stop flange.

Figure 6. 1977 modified radio whale tag system. Gun was balanced with weight added to stock and fore-end.

considerably more difficult, but into targets and even into the floating carcasses in Iceland, firing from the shoulder, it was possible to place successive tags within 20 cm of each other at 20 m. We used a well-balanced gun with weight added to both the stock and the fore-end, total gun weight of about 6 kg (Figure 6).

1977 Iceland Tests

For the 1977 tests on whale carcasses in Iceland, we planned to try different points to see if one shape would perform better than others, to compare the new modified tags with the 1976 tag, and to check the durability of components (such as antennas) that had previously failed. If these tests proved the system to be reliable, we then planned to use radio tags on live whales that were about to be caught by the Icelandic whalers to test for differences in penetration between the blubber of live animals and fresh carcasses. We then hoped to try the tags on whales that would not be caught immediately.

The experiments in Iceland were planned for the early part of their whaling season, so that information on the utility of the modified radio tag could be available for later experiments. Work on the ballistics of the tag and late arrival of test units from the factory delayed our departure until 10 July. Tags with live radio transmitters were not delivered before our departure, and did not reach us in

Iceland, so we did not try the system on live whales.

The 1977 tests in Iceland (Watkins and Moore) used 6 (dummy) tags, 2 pushrods of the right length (and 2 that were too long), and 2 each of 5 basic points. Three of the tags were lost after ricochets and one pushrod was stolen by a tourist. Each whale carcass was used for 3 or 4 shots, often placed 10 to 20 cm apart, so that we could make each series of shots as identical as possible except for the variable that we were testing at the moment. High-speed 16 mm moving picture photography, at 1200 pictures-per-second, was used to verify our results. Routinely the films from each series of shots were developed before the next tests.

We found that all of our modifications were improvements. Partly because of greater experience with the system, preparation for each shot took less time than it had in 1976, and the use of a line cannister (Figure 6) on the gun barrel was an improvement over the coiled line in a separate box. The pushrod line-ring survived 2 to 3 shots before deforming, and could usually be re-shaped with a file. The redesigned antenna survived all shots (at least 8 each) with no damage. We had no water leaks. The pushrod stayed on the tag during all good penetrations, often breaking only one of its 3 shear screws, but all the fastenings broke when a ricochet occurred. A shot into the water broke only 2 of the 3 screws so that the tag could be retrieved. The new spring-loaded fastening of the tag-to-pushrod connection continued to work well. Photographs of the tag consistently showed that it travelled along a relatively straight, repeatable trajectory. With point E, the wobble in the trajectory did not appear to be a problem, but it may have contributed to problems with other less successful points.

With points that permitted straight penetration, the tags often went in a little beyond the stop, depressing the surface of the blubber by 1 - 2 cm. As the pushrod pulled loose, however, the tag backed out by that amount so that the flange then rested against the surface of the whale. This was apparently the amount of backing-out needed to set the point barbs. Tags that penetrated initially only as far as the stop sometimes would pull back to protrude by 1 - 2 cm. When no screws were broken during implantation, the pushrod could exert as much as 35 kg of pull on the tag as the shear fastenings were broken loose. But once the barbs were set, even this amount of pull was insufficient to back the tags out any further (Figure 7).

Test of Points

The consistency of the results of the tests of different points lends weight to the comparisons we made, even though the number of tests was too small for statistical validity. The tests were limited by the amount of time we had to work with each carcass, and they were limited by the number of tag components that we had. Since a ricochet usually broke the tag loose from its pushrod and lost the tag in deeper water, we did not repeat shots with point shapes or angles of impact that resulted in a ricochet. For example, we only used the 1976 point twice in these tests, and could not afford to try it more; one was a ricochet that lost the tag, and the second took a very sharp turn in the blubber that snapped off the pushrod. In the same series, other points performed properly. We decided the 1976 point was at fault.

For the design of the point for the radio tag we had searched the literature and contacted those that might have dealt with these problems before, including manufacturers of harpoon equipment, and users and manufacturers of the "Discovery" whale mark (Brown 1962). We could find little information that proved useful. The Discovery mark and its occasional testing as well as its wide-spread use provided references to problems in "marking" whales but there apparently had been no comparative study of different point shapes or of the ballistics of the tags in air. An experimental study of the behavior of harpoon heads through water by Hirata (1951), found that the blunt point now used on most Discovery marks improved trajectories through water by providing an even pressure flow around the point. Therefore, these points were found to help reduce ricochets both off the water and off whale blubber.

Figure 7. Three 1977 radio whale tags in finback carcass, Iceland.

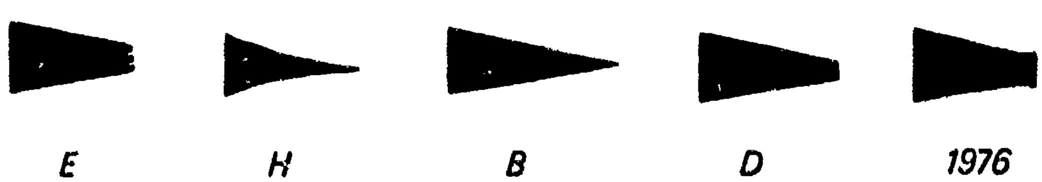

Figure 8. Points used in 1977 tests in Iceland, in order of performance (left-to-right).

Various types of harpoon points have been tried from time to time so that the whaling harpoon head currently used, for example, by the Icelandic whalers, has a blunt point with 4 small projections on the periphery of the tip. This head was said to ricochet off whale blubber less than other points.

The point chosen for the 1976 radio whale tag was derived by OAR from their assessment of harpoon points. It was a 20° tapered point with a shallow 1-cm cup at the end whose edges were sharpened to form a continuous cutting edge. (See drawing). We concluded from our 1976 tests that the cupped end was a mistake and that it probably contributed to some of the ricochets and erratic penetrations that we experienced. We suspected that the cup tended to build a high pressure area in front of the tag.

In our 1977 tests in Iceland, we tried 5 point shapes. The shoulder diameter of each was that of the 19-mm case of the radio tag. The points are listed in order of their performance (see Figure 8):

E— a 20° taper with cutting edges around a hollow 6 mm tip with channels to relieve the build-up of forward pressure.

Used 7 times in finbacks — all good.

Used 3 times in sperm whale — penetrated 2/3 or more, straight entry.

H— a sharp 25° point with variable pitch — a shorter and sharper tip than B.

Used 4 times in finbacks — 3 good, 1 ricochet at 20° impact angle.

Used 1 time in sperm whale — ricochet at 40° impact angle.

B— a 20° cone with a sharp tip.

Used 6 times in finbacks —2 good, 3 penetrated only partially (1 because of bone contact), 1 ricochet at 25° impact angle.

Used 1 time in sperm whale — turned and bent badly, though it penetrated well.

D— a blunt 20° taper with a 6 mm flat tip, somewhat like the point for the Discovery mark.

Used 5 times in finbacks — all penetrated, but all turned (upward) in blubber; 2 turned sharply to lodge just under the skin.

1976 Point — a shallow 10 mm cup at the end of a 20° taper — the point used for the 1976 tests.

Used 2 times in finbacks —1 ricochet at 30° impact angle, 1 turned sharply in blubber at 40° impact angle.

High-speed movies taken at 1200 pictures-per-second of most of these point tests provided good visual records of the experiments. Most of the movies were developed by hand after each series of shots in order to verify our impressions of the performance of each point. The pictures sometimes showed details that were different from those we thought we had seen. The photographs demonstrated the repeatability of the tag trajectory.

The only point that penetrated well and straight every time it was used was point E. It allowed the tag to penetrate fully with impact

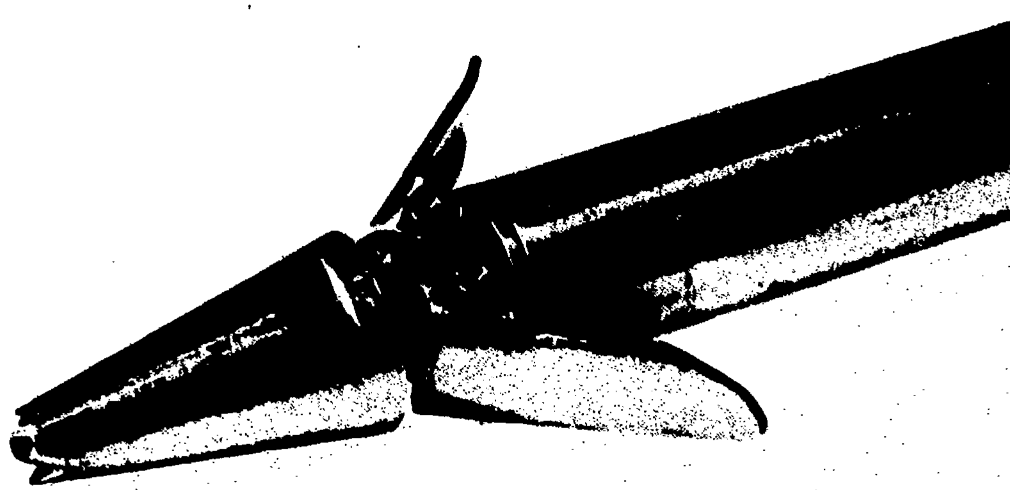

Figure 9. 1977 radio whale tag: point "E" penetrated well and straight every time.

angles as low as 20°, and it did not turn in the blubber. We had no ricochets with this point. It was used 7 times in finbacks and 3 times in sperm whale. It penetrated to the stop (29 cm) in all the finback shots and 20 cm or more in the sperm whale.

Point E included both cutting edges and pressure-relief channels and was designed to be relatively easy to fabricate. We wanted a point that would grab and begin penetration at low angles. The structure of blubber includes strong thread-like sinews, so we also wanted a point that could cut an area through these about 1/4 the diameter of the tag. We reasoned that this would lead the tag into the blubber straighter than points that simply pushed the material apart and took the path of least resistance. We also wanted to avoid the build-up of high pressures in front of the point as it moved through the blubber, and so four pressure-relief channels were cut from the cutting edge that rims the tip of point E. The form of this point is somewhat like the tip of the grenade head used by the whalers.

The sharp points ("H" and "B") were difficult (even dangerous) to handle in confined space, so we may not have given them as good a test as they deserved. But we were pleased to see that a more easily handled point (E) performed as well or better.

From our 1976 tests, we felt that higher impact angles of the tag trajectory relative to the surface of the whale would allow some penetration by nearly any point shape, but that it was at lower angles (perhaps more realistic at sea as well) that the differences between points could be noted. Our tests therefore were arranged for impact angles of 20 to 45°. Points that penetrated well at higher angles, often ricocheted at lower angles. It was, in fact, this feature that separated point E from the other points: it did not ricochet even at angles approaching 20°, the tip-to-shoulder angle for this point.

We had anticipated that point "D", the blunt point (Figure 10), would perform better than it did because of its similarity to the point

Figure 10. 1977 radio whale tag: with point "D". Tag has turned upward, just under the skin of a finback carcass.

that has been used for so long on the Discovery whale mark. Instead, it consistently turned after it entered the finback blubber, usually turning upward (estimated 10 to 40° from the impact trajectory) along the layer of blubber in the direction of the shot reducing the effective antenna angle. Presumably this point was forcing (not cutting) its way into the blubber and being turned toward less resistance at the surface of the whale by pressure build-up in front of the point. In Hirata's 1951 experiment the build-up of a water pressure wave in front of a flat point was considered advantageous because it overcame the bias of the rounded points which always turned in the direction of less potential pressure. The flat point in blubber, however, may build so much more pressure in front of it that (it effectively becomes a rounded point) it moves away from the area of high pressure in front of the point toward the lower pressure of the nearest surface.

As we noted in the 1976 tests, the skin and blubber of sperm whales was so much tougher than that of finbacks that our radio tag did not fully penetrate it. We tried 6 tags on sperm whale. With point H on the tag, we had a ricochet at 40° impact angle and lost a tag. With point B on the tag, the point bent badly on impact and the tag turned, but penetrated 25 cm. However, all 3 of the tags using point E penetrated straight and to a depth of 20 cm or more. By this time, we were running very short of tagging components and so stopped the radio tag tests on sperm whale carcasses because of the higher risk of damage to our remaining test units. With our best point we had only been able to penetrate sperm whale blubber by 2/3 of the length of the tag (Figure 11).

Comparison with Discovery Mark

We wondered how the point of the Discovery whale mark would compare with the points on our tag, and were fortunate to have access to a few Discovery marks supplied by the Icelandic Marine Research Institute. Unfortunately, by the time we were ready to try the Discovery marks, the available carcasses were all sperm whales, so we could not compare with our previous tests on finback carcasses. We shot 10 Discovery marks and compared their penetration at the same angles and distances with 6 of the radio tags using 3 different points (B, H, and E) that were shot into the same sperm whale carcasses. We also took high-speed (1200 pictures-per-sec) movies of the shots as they hit the whale.

The Discovery mark did not perform anv better than the radio tag. We shot 10 marks at impact angles of 30 to 45° from a distance of 25 m: only one penetrated into the meat (45° impact angle), 2 penetrated but turned inside the blubber (40-45° impact angle), 3 were protruders with 10 to 20 cm of the mark outside the whale (35-45° impact angles), and 4 were ricochets (30 to 40° impact angles). All but one of the 6

Figure 11. Discovery mark (upper left) and 1977 radio whale tag, with point "E", in sperm whale carcass.

Figure 12. Discovery mark, bent upon penetration of sperm whale carcass.

that were recovered had bent points. 3 were badly mashed out of shape, and the body of the mark was also bent in 2 of these. The bending and mashing occurred on impact with the whale; marks were not damaged on the flensing plan (Figure 12).

The high-speed photographic record demonstrated that the observers of the Discovery mark shots were often wrong about the marks' penetration — observers firmly indicated a ricochet for a mark that was later recovered, and they searched in vain in the meat for a mark that the film later showed to be a ricochet. The photographs clearly show a mark that was a ricochet whose point was bent sharply after impact with the whale. Other pictures show marks twisted and protruding from the skin. The orientation of the mark in flight was variable and probably contributed to its erratic penetration, especially at lower impact angles. The distortion of the point by the impact with the sperm whale skin must also have contributed to erratic penetration.

Conclusions

The radio whale tag appears to be ready for field trials on rorquals. The 1977 modifications were all improvements. The tag implants predictably and there were no component failures throughout the program of testing on whale carcasses in Iceland. We have sufficient experience with the system now to feel confident that the tag can be remotely attached to a whale, and that it will transmit if it is properly implanted. One point shape consistently penetrated straighter and better than the others we tried.

Equally as important, we also have learned enough to be able to identify some basic cautions. This radio tag is not useable on sperm whales. The site for the tag must be chosen with care to provide good antenna exposure and to avoid harming the whale. For most frequent as well as maximum antenna exposure, a site in the nape close behind the head should be chosen, though considerations of marksmanship may dictate implantation farther aft; flexure of the whale's body is minimum at the neck and maximum near the fin. Since the tag is slowed drastically by water, a hit through water should be considered a miss. Marksmanship will require judgment of distance for accuracy. The trajectory is not perfect so that minor variations in the system may trigger faulty implantation. Ballistics and the point are critical to acceptable penetration. Modifications to the tag need rigorous testing. The body of a whale proved to be very much more solid than any of the test targets we used. Earlier radio whale tags that do not include the 1977 modifications should not be used.

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We have appreciated the contribution of ideas and help in the development and field testing of the tag, particularly from those that had valuable experience in other radio tagging endeavors: William E. Evans, G. Carleton Ray, and Douglas Wartzok. Others participated in the trials of the tag on animals at sea, especially James H. Johnson, Michael F. Tillman, and Edward D. Mitchell. We have also appreciated the talents of Romaine Maiefski who has absorbed the brunt of the manufacturing details of the development, and Hugh B. Martin who has been responsible for the radio circuitry; both have encouraged the continuing involvement of Ocean Applied Research Corporation (San Diego) in the whale tagging program. G. Carleton Ray and Douglas Wartzok have contributed heavily to the development of the radio tag and particularly the launching system, through their contract at the Johns Hopkins University with NASA (NAS-2-9300). Realistic tests of the tag on whale carcasses in 1976 and 1977 were possible because of the generosity and helpfulness of Jón Jónsson of the Icelandic Marine Research Institute, and Kristján Loftsson with his expert crews at the whaling station of Hvalur H.F., Hvalfjördur. We particularly appreciated the helpfulness of Jóhann Sigurjónsson during both of our Iceland tests. Karen E. Moore has been directly involved in our experiments, has taken responsibility for the high-speed photography, has prepared the manuscript and taken most of the pictures for the figures. Support for the tag development and consistent encouragement has come from the Biological Oceanography section of the Office of Naval Research (Contract N 00014-74-C0262 NR 083-004).

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THE DEVELOPMENT AND TESTING OF A RADIO WHALE TAG
by William A. Watkins and William E. Schevill. 38 pages.
September 1977. Prepared for the Office of Naval Research
(Biological Oceanography Section) under Contract N00014-74-C-0262;
NR 083-004.

A 200 mwatt, 27 MHz radio whale tag has been developed for tracking whales at sea. It is remotely implanted and will transmit continuously for about 90 hours, equivalent to 16 weeks on a normally behaving finback. The tag has resulted from initial efforts to tag right whales with radios in 1961-1965. The tag and its launching system were tested on whale carcasses at the Icelandic whaling station in 1976 and 1977. One point shape consistently penetrated straighter and better than others we tried. With 1977 modifications, the radio whale tag appears to be ready for field trials on rorquals.

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